UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 5 1979

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Robert B. Minogue, Director
Office of Standards Development

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 65
RECONNAISSANCE BEDROCK GEOLOGIC MAP OF THE MARLBOROUGH QUADRANGLE, MASSACHUSETTS, AND RECONNAISSANCE BEDROCK GEOLOGIC MAP OF THE SHREWSBURY QUADRANGLE, MASSACHUSETTS

REFERENCES:
1. Letter W. R. Stratton to Dixie Lee Ray dated May 16, 1973. Subject: Report on Seismic Research.
2. Title 10, Chapter 1, Part 100, CFR Appendix A - Seismic and Geologic Siting Criteria for Nuclear Power Plants.
3. Memorandum N. B. Steuer to R. J. Mattson dated July 15, 1975. Subject: U.S. Tectonic Province Map.

INTRODUCTION

This memorandum transmits "Reconnaissance Bedrock Geologic Map of the Marlborough Quadrangle, Massachusetts," and "Reconnaissance Bedrock Geologic Map of the Shrewsbury Quadrangle, Massachusetts." The research effort to produce these maps was begun prior to 1976 as a U.S. Geological Survey (USGS) project. P. J. Barosh of the Weston Observatory of Boston College, who had worked on the project for the USGS, completed the maps under NRC funding. The maps and formation descriptions are available as a USGS open file report, and are appended in their entirety to this Research Information Letter. The New England Seismotectonic Study is a planned 5-year program to study the geology and seismicity of New England and contiguous areas to assess the potential seismic hazard to prospective nuclear power plant sites in the region.

SUMMARY

The "Reconnaissance Bedrock Geologic Map of the Marlborough Quadrangle, Massachusetts," and the "Reconnaissance Bedrock Geologic Map of the Shrewsbury Quadrangle, Massachusetts," are products of the New England Seismotectonic Study which is a program of investigations to better understand the manifestations and causes of seismicity in New England and adjacent areas to assess the seismic hazard in the region. The study, which began July 1, 1976, is a cooperative effort with several universities and State Geological Surveys. It is principally funded by the U.S. Nuclear Regulatory Commission. The first year's program directly involved six investigators from Boston College, Bowdoin College, the University of Kentucky and the State Geological Surveys of New York and Connecticut.

The initial effort: (1) compiled and analyzed available pertinent information on seismicity, geology and geophysics in the region; (2) acquired new information by investigating previously identified problems; and (3) developed and organized a comprehensive program that in 5 years should provide an assessment of the seismic hazard of the region.

The program will integrate seismological, geophysical, geological, and remote-sensing studies to complement the program of the Northeastern U.S. Seismic Network. The program is designed to provide: (1) regional information needed to acquire a general understanding of seismicity and its relation with geologic and geophysical features and to delineate seismotectonic provinces; and (2) more detailed data in the areas of higher seismicity to attempt to reveal specific relations of seismicity with geology and to identify active features. Regional and site studies will evaluate hypotheses to explain the causes of earthquakes in the region.

The Study is coordinated with, and complementary to, the cooperative programs of the Northeastern U.S. Seismic Network, funded by both the U.S. Nuclear Regulatory Commission and the USGS. The network maintains seismograph stations and monitors earthquakes in the region. Complementary projects in the region include the studies on the Clarendon-Linden fault zone, present day vertical uplift of the Adirondack Mountains, compilation and study of brittle structures of New York by the New York Geological Survey and the seismic array investigations in New York by the Lamont Doherty Observatory.

Results thus far document the importance of faulting in the region and demonstrate the effectiveness of remote-sensing, magnetic-lineament and gravity-lineament analyses to reveal faults in the region. Report manuscripts (which are now being processed) of studies partially funded by the U.S. Nuclear Regulatory Commission, include: "The Preliminary Bedrock Geology of the Boston 2-Degree Sheet," "Bibliography of Seismology of the Northeastern United States," "Bedrock Geology of the Cape Ann Area, Massachusetts," "Preliminary Bouguer Gravity Map of Onshore-Offshore Northeastern United States and Southeastern Canada," "Bedrock Geology of the Worcester Region, Massachusetts," "Regional Bedrock Geology of the Moodus Area, Connecticut," "Bedrock Geology of the Eastern Half of the Portland 2-Degree Sheet," and "Interpretation of Aeromagnetic Data in Southwest Connecticut and Evidence for Faulting Along the Northern Fall Line."

The program includes studies of remote-sensing, gravity, magnetics, fracture analysis, reanalysis and cataloging of instrumental data on earthquakes, and both detailed and reconnaissance geologic mapping. The State Geological Surveys of New York, Connecticut and Maine, and personnel from Bowdoin and Boston Colleges, the Universities of Rhode Island, Massachusetts, Kentucky and Delaware, and the Rensselaer Polytechnic Institute are participating.

The prudent selection of nuclear power plant sites must consider the seismic hazard and designate appropriate gravity acceleration values for construction standards. Such selection requires more comprehensive understanding of the structure and tectonics of the region and their relationship to the seismicity than is presently available. The current practice of selecting a site without this information, followed by an extensive investigation of the region, is a slow and costly procedure, especially when faults are discovered near the site during such an investigation.

Gravity acceleration values chosen for construction standards for nuclear power plants are based on the maximum established earthquake intensity or magnitude. When information is insufficient to judge the earthquake hazard, the values may be set too low for adequate safety or too high, and raise construction costs needlessly. The seismicity in New England varies greatly from place to place (Boston Edison, 1976; Hadley and Devine, 1974) (Figures 1 and 2) and a scientific approach must be used to determine appropriate acceleration values within the region. A thorough study of the structure, tectonics, and seismicity of the region and their relationships is required to obtain the information. The level of seismic activity has varied in the past 300 years (Shakal and Toksoz, 1977), but the locations of the most active areas appear to have remained about the same (Figures 1, 2, and 3).

New England is not in the most seismically active belt in the United States, but seismic activity has been recorded in the region since the first English settlers, and before that, one locality, Moodus, Connecticut, was sacred to the Indians due to the numerous earthquakes there. The 1775 earthquake, estimated at about intensity VIII, off Cape Ann, is the largest recorded seismic event in the region (Figure 1), and largely because of it, the Coast and Geodetic Survey placed the Boston region in the highest seismic risk category.

Early USGS workers recognized the highly faulted nature of the region, but most workers in the region concentrated on mineralogic and related studies, and little was done to unravel the fault structure. Hobbs, in the early 1900's, recognized the probable regional extent of the faulting, based on lineament studies (Hobbs, 1904). He also suggested a relationship between these regional faults and seismicity, especially at fault intersections.

Extensive faulting in the region has been slowly revealed, mainly through quadrangle mapping by the USGS and through mapping tunnels and expressway roadcuts. Recently, geophysical and remote-sensing data have revealed more faults and possible faults both onshore and offshore. The more detailed structural and tectonic framework shows an improved fit with the epicentral maps of the region and suggests further work would lead to a much greater understanding of the regional seismicity and earthquake mechanisms.

At present, most of the mapped faults have been compiled for New York and southern New England (Isachsen, 1977; Barosh, Pease, Schnabel, Bell, and Peper, 1977) and a very preliminary compilation has been made for all the New England region

(Barosh, 1976). Evidence for post-glacial faulting in the region has been summarized (Woodworth, 1907; Oliver, Johnson, and Dorman, 1970). Interpretation of the aeromagnetic data has been done in a general way for all of southern New England with more detailed studies at some places. Landsat and Skylab analyses have been done for New York (Isachsen, 1977; and Isachsen, et. al., 1974) and SLAR lineaments have been drawn for southern New England (Banks, 1974). Several very small-scale tectonic maps (Rodgers, 1970), containing little fault data, cover the region, but the generalized small-scale map of Hadley and Devine (1974) is the only seismotectonic map available. Much of what has been done is in the general nature of preliminary work and should be refined. In addition, a great deal of geophysical, remote-sensing, and geologic data is presently available for analysis and synthesis.

BACKGROUND

In 1973 (Ref. 1), the ACRS recommended that investigations be initiated to determine the reasons for, and source of, earthquakes in areas of the eastern U.S. where large shocks have occurred.

This recommendation also was in part brought about by Appendix A, 10 CFR Part 100 (Ref. 2), which establishes requirements for seismic and geologic site investigations for nuclear power plants and associated nuclear facilities necessary for evaluation of the site and for providing information needed for engineering designs. Paragraph (6), Section IV of Appendix A requires that, where possible, epicenters of historically reported earthquakes be correlated with tectonic structures, any part of which are within 200 miles of the site, and that epicenters or locations of highest intensity which cannot reasonably be correlated with tectonic structures should be identified with tectonic provinces, any part of which are within 200 miles of the site.

This part of the Regulation was developed to take into account the fact that tectonic settings of the eastern U.S. are significantly different from those of the western U.S. The Regulation does not provide guidance in the form of a map to establish seismotectonic provinces in the East. This has resulted in lengthy licensing delays because of the time needed to resolve controversies among applicants, the public and NRC regarding tectonic province boundary locations.

In 1974 the Office of Standards Development undertook an effort to develop an eastern U.S. Seismotectonic Province Map; however, when the map was completed, there was a consensus opinion that it was not adequate to clarify Appendix A to 10 CFR which requires the tectonic province approach. There remained specific information needs to be satisfied in order to develop a map which will be a useful regulatory tool. That is, more geologic data and seismologic input are needed to more accurately delineate eastern U.S. seismotectonic provinces. Consequently, the cooperative geologic and seismic programs were undertaken with state geological surveys and universities to gather regional data to: (1) help delineate tectonic provinces; (2) identify earthquake source mechanisms; (3) improve knowledge of regional geologic conditions; (4) provide data to confirm past licensing decisions; (5) expand the existing geologic and seismic data base; and (6) to provide a consistent data base.

Approximately 23 state geological surveys and universities are cooperating under NRC funding to provide data needed to develop a data base for an eastern U.S. seismotectonic province map. The studies are being conducted in three phases: Phase I -- existing data compilation (complete), Phase II -- new data acquisition, and Phase III -- problem areas of the eastern U.S. and a seismotectonic provinces map. Many of these cooperative programs were funded initially by the Office of Standards Development (Ref. 3). Later, the program responsibility was transferred to the Office of Nuclear Regulatory Research because of their long-term nature.

CRITERIA FOR STUDY AREA SELECTION AND OBJECTIVES OF STUDY

The northeastern United States has a number of population centers that have undergone rapid growth during the period since the second World War. This increased growth, in conjunction with the increase in fossil fuel costs, has stimulated electrical generation companies to consider nuclear power plants as a viable means to provide additional energy. There are, at the present time, 19 operating, 15 being built, and 9 planned nuclear power plants in the northeastern U.S. Many of the existing and proposed plants are located within or adjacent to an area which has been designated as seismic risk zone 2, an area having had earthquakes with resulting moderate damage and corresponding to seismicity up to MM VII.

NRC rigorous guidelines must be adhered to before a permit to construct a nuclear power plant is granted to an applicant. Local, as well as regional seismicity and structural relationships play an integral role in the final design criteria for nuclear power plants. This requires that a value for the maximum expectable seismic event be assigned at a proposed site. The existing historical record of seismicity is inadequate in a number of areas of the northeast region because of the lack of instrumentation and/or the sensitivity of the instruments deployed to monitor earthquake events. This inadequacy has made it necessary to rely on the delineation of major tectonic provinces that are based on broad regional geologic structures and associated seismicity. The delineation of tectonic provinces which accurately reflect the potential magnitude of seismic events is an important cost and risk factor in assigning appropriate design criteria for nuclear power plants.

Many earthquakes have occurred in the northeast and they have, in the past, been ascribed to crustal adjustment. Little is known about the relationships of these structures, and this project will be a part of a larger study effort to investigate their possible interaction.

The objectives of the project are to delineate northeast seismotectonic provinces and associated structures, to investigate the relationships between the structures and seismicity, and to assign realistic values for maximum seismic magnitude in the region.

PLANNING

A 5-year multidisciplinary study is planned. The study will outline the geology, structure, tectonics and seismicity of the northeastern U.S.

Project work is planned in three separate but interrelating phases, which are:

1) Existing data synthesis;

2) Acquisition of new data, seismic network installation and operation; and

3) Final synthesis of new and old data, interpretation, map and report preparation.

This interim report presents results of work completed in Phase I.

These maps were developed as a result of field and laboratory studies conducted over a period of years by the USGS in cooperation with the State of Massachusetts. Much of the field work was conducted by the author while he worked for the USGS. He subsequently synthesized the data and developed the enclosed maps in their present form under an NRC contract. The faults and other geologic structures identified will be used to correlate with other geologic features in the northeast so that seismotectonic boundaries can be identified. Additionally, an attempt will be made to determine how the structures relate to the area's seismicity.

RESULTS

The principal results of the study are the subject bedrock geologic maps.

RECOMMENDATIONS

It is recommended that the Marlborough and Shrewsbury Quadrangle Maps be considered by the Office of Standards Development and the Office of Nuclear Reactor Regulation as input to the development of a tectonic province or seismic zoning map of the eastern U.S., and to provide a basis and guide for ongoing studies in the area.

Additionally, RES recommends that studies and data gathering activities be continued in this area so that we may better understand the geology and seismicity of the eastern U.S.

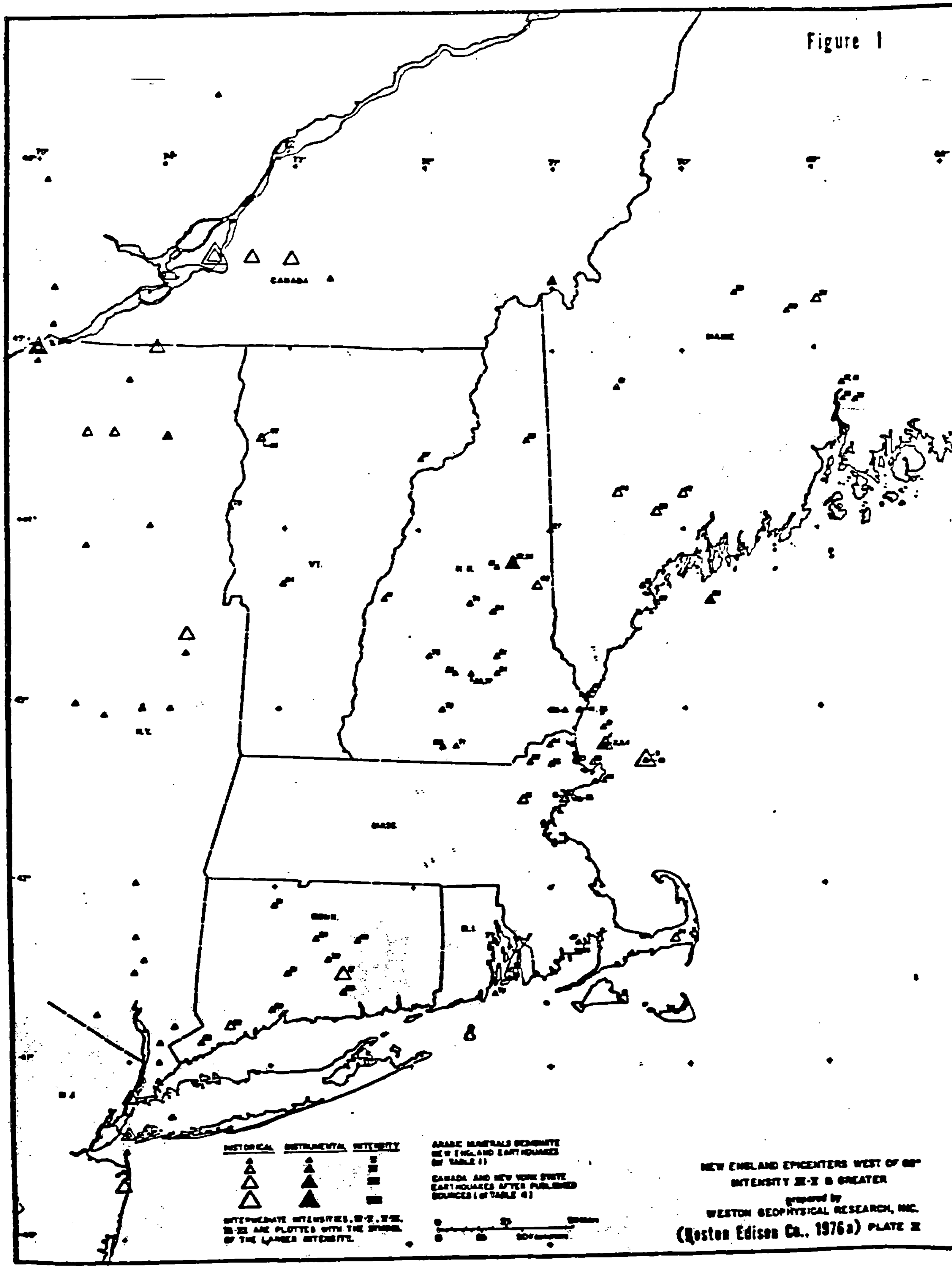
It is also recommended that the researchers make annual oral presentations to all NRC geologists and seismologists so that work progress can be discussed and the programs redirected or modified, if necessary.

Technical questions concerning "Reconnaissance Bedrock Geologic Maps of the Marlborough and Shrewsbury Quadrangles, Massachusetts," may be directed to Neil B. Steuer at 427-4370.

Saul Levine
Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Figure 1
2. Figure 2
3. Figure 3
4. Marlborough Map
5. Shrewsbury Map

Figure 1


CANADA
MAINE
VT.
N.H.
N.Y.
MASS.
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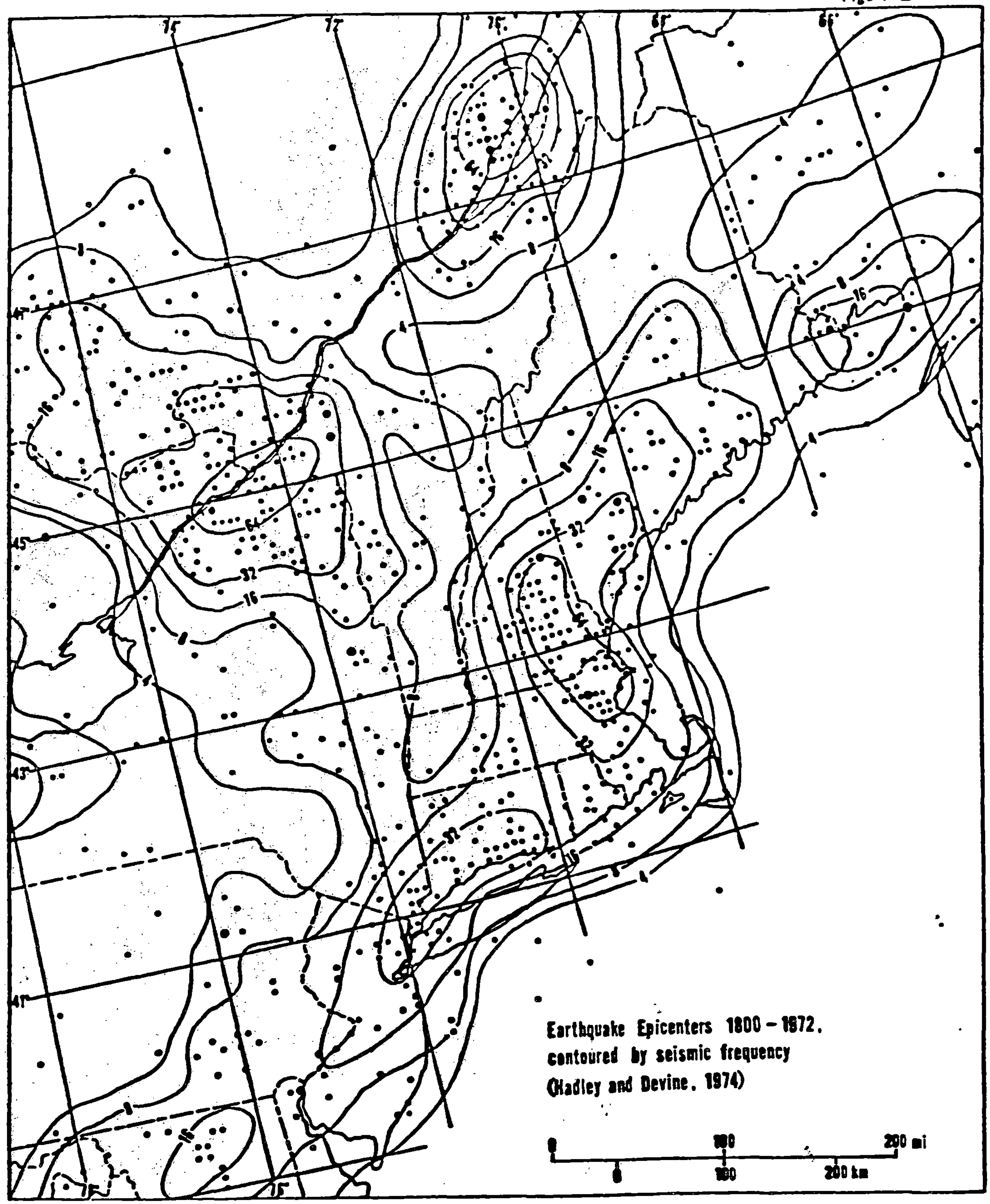
HISTORICAL
INSTRUMENTAL
INTENSITY
ARABIC NUMERALS DENOMINATE
NEW ENGLAND EARTHQUAKES
OF TABLE I
CANADA AND NEW YORK STATE
EARTHQUAKES AFTER PUBLISHED
SOURCES (of TABLE 4)
INTERMEDIATE INTENSITIES
ARE PLOTTED WITH THE SYMBOL
OF THE LARGER INTENSITY.
NEW ENGLAND EPICENTERS WEST OF
INTENSITY
& GREATER
prepared by
WESTON GEOPHYSICAL RESEARCH, INC.
(Boston Edison Co., 1976a) PLATE

Figure 2


Earthquake Epicenters 1800 - 1972.
contoured by seismic frequency
(Hadley and Devine, 1974)
0 100 200 mi
0 100 200 km

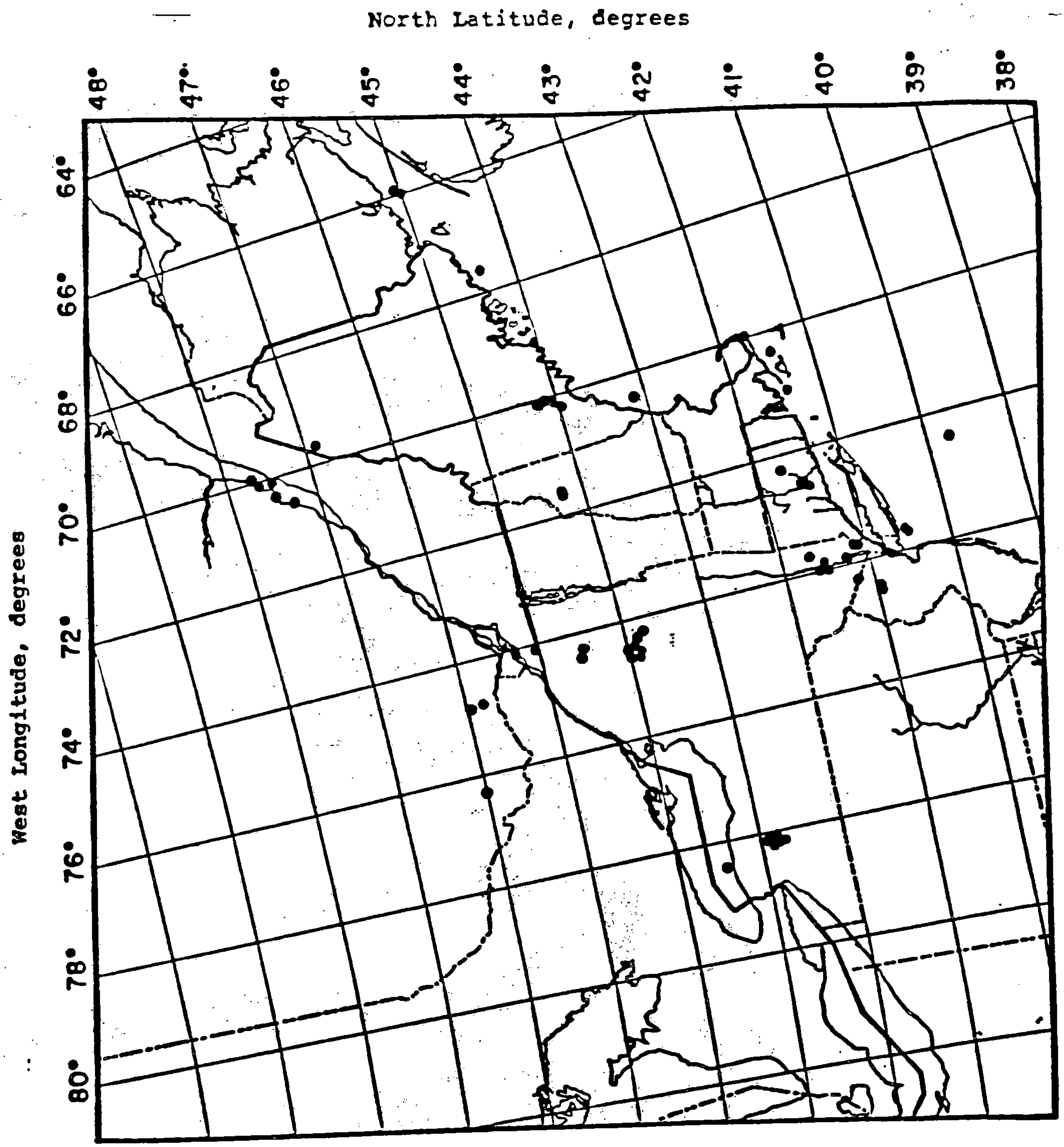


Figure 3. Earthquake epicenters during the period October 1975 - September 1976.
(Northeastern U.S. Seismic Network Bulletin No.4, 1976)

Harold R. Denton
Robert B. Minogue

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Original Signed By
Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosures:
1.. Figure 1
2. Figure 2
3. Figure 3
4. Marlborough Map
5. Shrewsbury Map

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